Mojave Desert Tortoise (*Gopherus agassizii*)
Sonoran Desert Tortoise (*Gopherus morafkai*)

The desert tortoise was selected as a core conservation element for the Sonoran Desert REA because it is an iconic species of the region that reflects inter-regional variability in climate, landform, and vegetation. The tortoise is a good indicator of desert condition because it is widely distributed across the ecoregion and, at the same time, sensitive and vulnerable to multiple disturbance factors. The desert tortoise inhabits desert environments in the Mojave and Sonoran deserts in southern California, southern Nevada, Arizona, southwestern Utah, and northwestern Mexico. Once recognized as a single species (*Gopherus agassizii*) with two recognized populations, it has recently been split into two species (Averill-Murray 2011). The Mojave desert tortoise occurs north and west of the Colorado River and retains the Latin name *Gopherus agassizii*. It was listed as threatened in 1990 and, 22 years after listing, the species is still declining, particularly in the western portion of its range in California (Brussard et al. 1994, Tracy et al. 2004, USFWS 2008, 2011). The Sonoran population is now called *Gopherus morafkai*, distinguished from *G. agassizii* by its physical features, different habitat, life history traits, and DNA evidence (Murphy et al. 2011). The Sonoran desert tortoise occurs east and south of the Colorado River, from Arizona into Mexico. REA results produced maps for current status and future condition for the two desert tortoise species.

Current Distributions

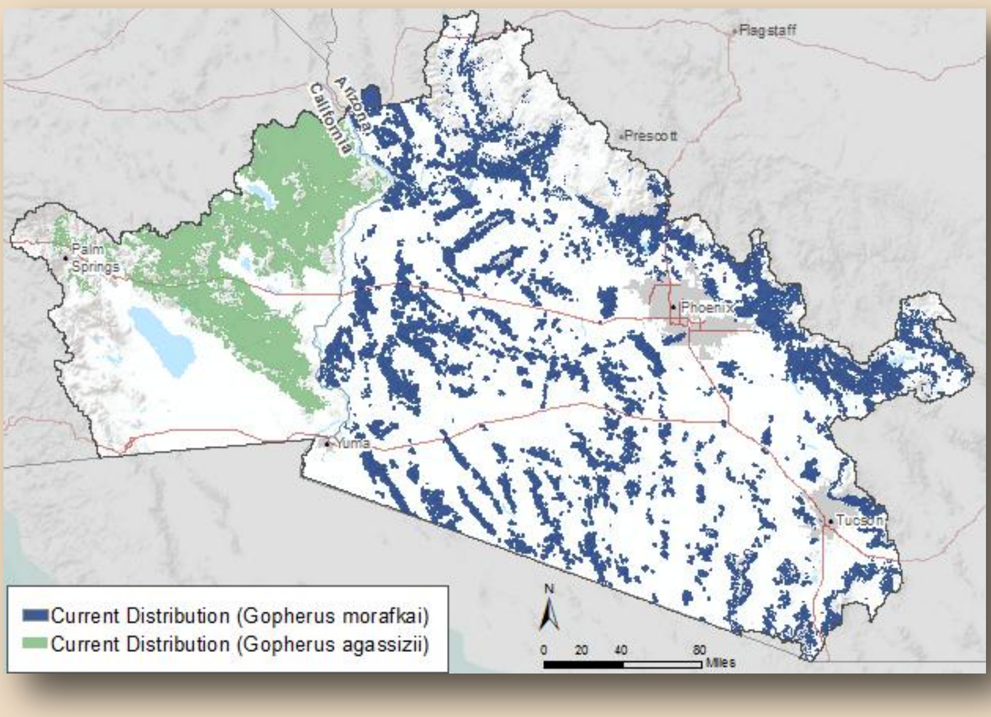


Figure 1. Potential distribution of the Mojave desert tortoise (*G. agassizii*) in green (based on a model developed by Nussear et al. (2009) and the Sonoran desert tortoise (*G. morafkai*) in blue. Map answers the management question: What is the most current distribution of available occupied habitat for desert tortoise?

The distribution of the Mojave desert tortoise is based on a predicted habitat distribution from an existing MaxEnt model developed by Nussear et al. (2009, Figure 1, green) for a wider region including the Mojave Desert of Nevada and Utah. The U.S. Geological Survey is developing another MaxEnt model for predicted habitat for the Arizona distribution of the Sonoran tortoise. In the meantime, for this REA, data was acquired from Arizona GAP (Arizona Game and Fish Department) for the distribution of the Sonoran desert tortoise (Figure 1, in blue).

Mojave Desert Tortoise (*Gopherus agassizii*)

Photo: Mojave desert tortoise. K. Nussear, U.S. Geological Survey

The Mojave desert tortoise occurs mainly in creosote bush (*Larrea tridentata*) flats, but it is also found in salt desert scrub and on sloping terrain on alluvial fans or foothills. It forages mostly on annual plants produced by winter rains. The yearly life cycle of the Mojave desert tortoise is heavily influenced by the annual precipitation pattern in the western Sonoran (and Mojave) Desert—precipitation that mainly falls in the winter and early spring with little or no summer precipitation (Van Devender 2002, Dickinson et al. 2002). As a result, most Mojave tortoise activity takes place in the spring when winter annuals and spring grasses are readily available (Nagy and Medica 1986, Brussard et al. 1994). Mojave tortoise hatchlings may overwinter in their nest and may not eat fresh forage until the following winter or spring. In years of low winter rainfall, Mojave tortoises may feed on introduced annual grasses in the absence or scarcity of winter annuals (Esque 1994), and while it is known that a diet of invasive grasses will keep tortoises alive, it is unknown if over time such a diet will keep them fit (Esque et al. 2002).

The species faces the prospect of annual summer drought; in the hot summer months and through the winter, the tortoises spend many months of inactivity in burrows in estivation or hibernation without eating or drinking. Mojave tortoises actively dig their own burrows in the friable soils of the western Sonoran Desert's basins and alluvial fans; they have the opportunity to alter the depth and extent of burrows to provide optimal thermal refuge and proper nest temperatures. Mojave desert tortoises typically burrow under shrubs in coarse sandy or loamy soils; they will also burrow under rocks, layers of caliche (as in the photo below), or even cement slabs in disturbed areas (Andersen et al. 2000, Lovich and Daniels 2000). Tortoises use multiple burrow sites that may vary in aspect throughout the year; burrows are often located under shrubs for shade, thermal cover, and protection from predation (eggs and juveniles, Lovich and Daniels 2000).

Because the species is at the northern limit of the overall range of desert tortoise species and because of their dietary restraints and restricted access to water, the Mojave desert tortoise may be more vulnerable to mortality from drought, loss of condition, and other stressors than the Sonoran desert tortoise (Peterson 1996, Oftedal 2002). The harsher conditions of the western Sonoran Desert ecoregion are reflected in the demographic characteristics of Mojave tortoises: individuals mature earlier reproductively and have a shorter life span than the Sonoran tortoises (Curtin et al. 2009). Curtin et al. (2009) admit that relatively fast growth and early reproduction in a harsh environment may be counterintuitive, but that such a life history strategy may have a selection advantage in populations with high juvenile mortality and shorter overall life span.

Case Study No. 1

Photo: Mojave tortoise in its burrow. S. Schwarzbach, U.S. Geological Survey

Although similar threats and disturbances affect both tortoise species, there are differences related to their varying life histories and habitats (Curtin et al. 2009). For example, as a lowland tortoise, Mojave tortoise inhabits more developable flatlands and basins in fast-developing areas of California's Sonoran Desert; as a result, it is more directly threatened by displacement from urban, agricultural, and energy development than the Sonoran tortoise that frequents the rocky slopes of the Arizona Upland (also see development section below). The fragmentation of habitat through rural housing and energy development affect tortoise populations not just through direct alteration of habitat but also through providing infrastructure and amenities that benefit predators of juvenile tortoises (Doak et al. 1994, Boarman 2003). Residential development, roads, and landfills favor tortoise predators such as ravens, coyotes, and feral and domestic dogs. For example, during a 25-year period in the late 20th century, some Mojave and California Sonoran raven (*Corvus corax*) populations in recently developed areas increased by 450-1000% (Boarman 2003). Piles of tortoise shells (incriminating evidence) have been found under raven nests (Boarman 2003). In contrast, Boarman and Coe (2002) found that raven densities were low in the roadless portions of Joshua Tree National Park.

Desert tortoises in the Mojave Desert suffer more than Sonoran desert tortoises from the upper respiratory tract disease (URTD) mycoplasmosis. Losses from this disease were one of the reasons for listing the Mojave species as threatened under the Endangered Species Act in 1990 (Van Devender 2002, USFWS 2008). For the Mojave tortoise, the frequency and intensity of URTD may be influenced by the effects of other disturbances. Habitat degradation, drought stress, food shortages, and crowding may all affect the onset and severity of URTD infections (Tracy et al. 2004)

Declines in Mojave desert tortoise continue even though tortoise management areas have been established and some of the major disturbances in those areas have been excluded. Prospects for recovery of Mojave desert tortoise are bleak if threats to both adult and juvenile segments of the population are not reduced. Doak et al. (1994) found that the rate of desert tortoise population growth was most sensitive to the survival of large adult females, and they proposed that improving survival of adult females could reverse population declines. Tracy et al. (2004) observed that the threats to desert tortoise are interactive and synergistic, and that recovery management required attention to factors affecting other age classes as well, such as the increase in predation on juvenile tortoises.

Case Study No. 1

Sonoran Desert Tortoise (*Gopherus morafkai*)

Photo: Sonoran desert tortoise (*G. morafkai*), Arizona Game and Fish Department

Sonoran desert tortoises live on the rocky slopes and bajadas of Arizona east of the Colorado River in the Arizona Uplands and northwestern Mexico. There is a wide range in tortoise densities across the Sonoran Desert depending on habitat conditions and food availability; Sonoran tortoise populations may range from 15–100 adults/mi^2 (Averill-Murray et al. 2002). Home range sizes also vary, but a typical female tortoise home range in Arizona is 10 ha; males' territories may be larger, overlapping the range of several females (Van Devender 2002, Averill-Murray et al. 2002). The species does occur on occasion and in low densities in the valleys (USFWS 2010), but the frequency of dispersal of young or adults between mountain ranges is unknown. It appears that the Sonoran desert tortoise, with its patchy distribution, may have fewer opportunities for maintenance of genetic diversity and dispersal than the Mojave tortoise, which has greater continuity among populations across the broad basins of the Colorado Desert (disregarding fragmentation and human disturbance factors, Van Devender 2002, Hagerty et al. 2011).

Sonoran desert tortoises construct burrows under shrubs and rocks or in caliche caves; the tortoise may expand existing crevices under rocks, but the rocky soil does not permit the extent of burrowing that occurs in the more friable soils of the Colorado Desert. Desert washes are important to this species as they provide exposed banks with variable aspects, exposed caliche caves for locating burrows, and xeroriparian vegetation for thermal cover (Riedle et al. 2008). Unlike the Mojave tortoise that estivates in its burrow during the summer drought, the Sonoran tortoise is active in the summer during the monsoon season when fresh forage is available. Eggs usually hatch at the end of the summer rainy season, meaning that hatchlings have more access than Mojave tortoise hatchlings to fresh forage in most years (Averill-Murray et al. 2002). Besides summer annual forbs, the Sonoran tortoise feeds on warm season grasses such as big galleta (*Pleuraphis rigida*), bush muhly (*Muhlenbergia porteri*), and threeawns (*Aristida* spp.). These grasses become sparser to the west where the summer monsoon rains dwindle; as a result, Sonoran tortoises living on the drier mountain ranges closer to the Colorado River subsist on alternate food sources more similar to those available to Mojave tortoises (Van Devender 2002).

The eggs and young of both species of tortoise are subject to heavy predation by a range of mammal and bird species as well as other reptiles (e.g., Gila monsters). With their soft shells, the young are rather defenseless, and they also must spend a greater proportion of their time foraging, exposing them to predation (Morafka 1994). Raven predation, however, may not be as high for tortoises in Arizona as it is in California; the increases in raven populations subsidized by development have not (yet) occurred to the same extent. Bird predation on tortoises in general may be less in much of tortoise habitat in Arizona because of the greater cover provided by denser upland vegetation (USFWS 2010).

The greatest human-induced threats to Sonoran desert tortoise are urban and exurban development, associated road building and highway upgrading, and the increasing demands of a larger population on outdoor recreation. Throughout the 1990s the urban fringe in Phoenix advanced outward at the pace of ½ mile per year (Rex 2005). Population projections for the Phoenix areas for the next 5 decades envision a 1–1.5 million increase per decade (assuming sufficient water availability, Rex 2005). Although urban development in lowland areas may not directly convert tortoise habitat on slopes and bajadas, it puts human influence and activities in closer proximity to tortoise habitat, increasing overall access, recreation use, harassment, and pet predation. Even if valley dispersal among populations is not common, it may be important to genetic diversity; barriers from development between mountain ranges create closed populations that, if degraded or damaged, will not have the ability to recover through recruitment from other populations (USFWS 2010). In 2010 the US Fish and Wildlife Service found that listing the Sonoran population of the desert tortoise was warranted, but that listing was precluded by higher priority actions (USFWS 2010). As a result, the Sonoran population of the desert tortoise was added to the candidate species list, where its status will be reconsidered annually.

Change Agents Affecting Both Species

Photo: Desert tortoise contemplates a road crossing.
W. Boarman, U.S. Geological Survey

Tortoises are directly threatened by humans in myriad ways including conversion of tortoise habitat by development, fragmentation and degradation of habitat by road networks and ORVs, vandalism, and direct mortality from collisions with vehicles on roads and ORV trails. Habitat fragmentation and barriers to movement created by interstate highways and canals can severely limit desert tortoise populations as well (Edwards et al. 2004). Off-road vehicles (ORVs) destroy and degrade habitat, crush burrows, and kill tortoises. Although both habitat damage and direct mortality may occur, habitat damage is the most strongly established effect of ORV use (Bury and Luckenbach 2002). Vandalism and intentional killing was a factor in listing the Mojave tortoise; at long-term monitoring plots in California, 14% of carcasses found between 1976 and 1982 contained evidence of gunshot wounds (Berry 1986).

Grazing practices affect tortoise populations through direct competition for the tortoise's herbaceous food plants and the general decline in abundance and species diversity in annual and perennial forbs that occurs over time in grazed areas. Grazing pressures that create a decline in diversity of winter annuals and fresh spring forage affect Mojave tortoises, while the general decline in C_4 (warm season) grasses in the Arizona Upland has adverse nutritional consequences for Sonoran tortoise, particularly when the forbs and grasses are replaced by invasive annuals. Although evidence suggests that Mojave tortoises might be more directly affected by grazing animals through soil compaction and trampling of their earthen burrows, a field survey of Sonoran tortoises in the Black Mountains of Arizona recorded almost 200 trampled burrows (Woodman et al. 1998). Both grazing-induced changes in species composition and trampling promote the invasion of nonnative plant species (USFWS 2010).

Photo: Young saguaro overtopped by buffelgrass in Saguaro National Park, National Park Service.

Development and road building also facilitate the spread of invasive annual plant species that introduce more frequent fire to desertscrub communities, which are not fire-adapted. Red brome (*Bromus rubens* subsp. *madritensis*) and buffelgrass (*Cenchrus ciliaris*, syn. *Pennisetum ciliare,* photo left), for example, directly reduce plant diversity, forage quality, and habitat structure (shrub thermal cover) for desert tortoise and produce fine fuels that carry intense and extensive fire (Brooks and Esque 2002, Esque et al. 2003, Esque et al. 2004). Dense stands of Sahara mustard (*Brassica tournefortii*) may also carry fire (especially when mixed with red brome, Brooks and Minnich 2006) and the dense growth of the mustard creates physical barriers to tortoise movements (see further discussion of fire and invasive species in Section 4.3, Change Agent Distribution and Intensity). The fire season for Mediterranean annuals (like red brome) peaks in the hot fore-summer season in May; the perennial grass (i.e., buffelgrass) fire season is longer, from October to the following July (Esque et al. 2002).

From 1990–2008, approximately 164,800 acres (66,690 ha) of desert tortoise habitat in Arizona burned on BLM lands (USBLM in USFWS 2010). The U.S. Fish and Wildlife Service (2010) estimates that 1.5% of tortoise habitat has been affected by wildfire in recent years over all ownerships in Arizona. Direct effects of fire in desert habitats include animal mortality and loss of vegetation cover. Although tortoises may escape fire in underground burrows, direct mortality from intense and slow-moving grass-fueled fire has been documented in the Sonoran Desert (Esque et al. 2003). Esque et al. (2003) estimated that 11% of adult desert tortoises present in the area of a fire at Saguaro National Park near Tucson, Arizona had died. Indirect effects of fire on tortoises may include increased predation and loss of thermal cover from the standing biomass of shrubs, desert trees, and cacti that supplement their network of burrows and rock shelters, although such effects may be species- or region-specific (Lovich et al. 2011a). However, loss of thermal refugia could lead to direct mortality if tortoise body temperatures exceed 40° C (104° F, Esque et al. 2002).

Current Species Status and Near-Term Development Scenario (2025)

Current status was evaluated for each wildlife species conservation element included in the REA by overlaying the species' current distribution against the overall current terrestrial intactness model—a regional model combining data for vegetation-habitat distribution, development, and natural habitat fragmentation patterns. (For maps of regional current landscape intactness, see Section 4.2.1.) The product is a map of ranked classes of status within both tortoise species' distributions (Figure 2). The distribution of the Mojave desert tortoise (*G. agassizii*) is from a potential habitat model by Nussear et al. (2009) and the distribution of Sonoran desert tortoise (*G. morafkai*) originated from the Arizona Game and Fish Department.

Case Study No. 1

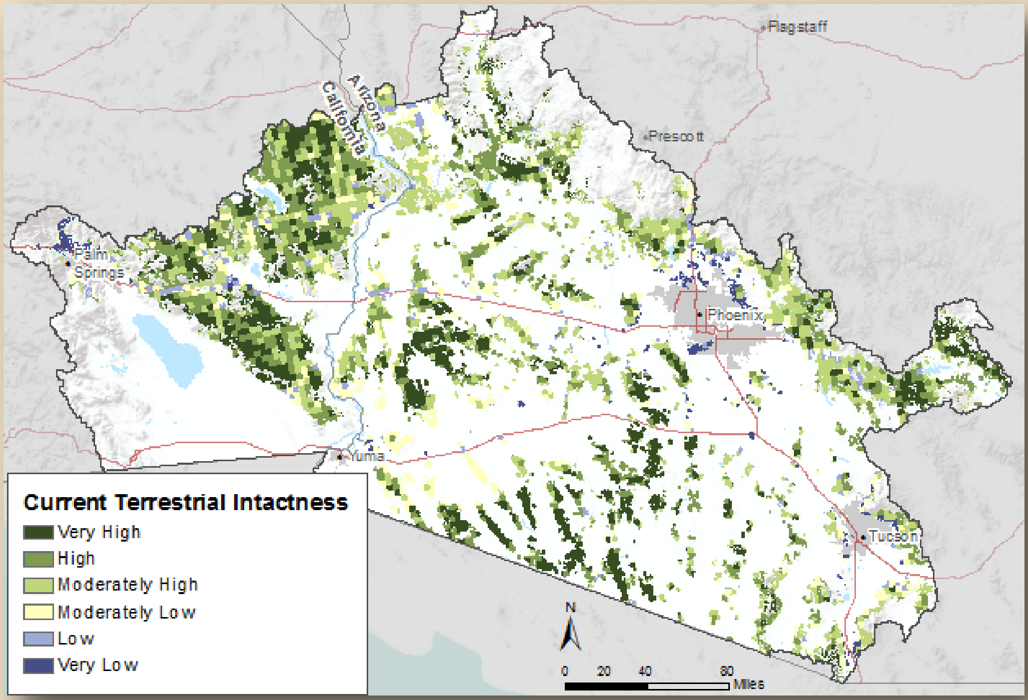


Figure 2. Current status for both Mojave desert tortoise (west of Colorado River) and Sonoran desert tortoise (east of Colorado River). See Figure 4 below for summary histograms.

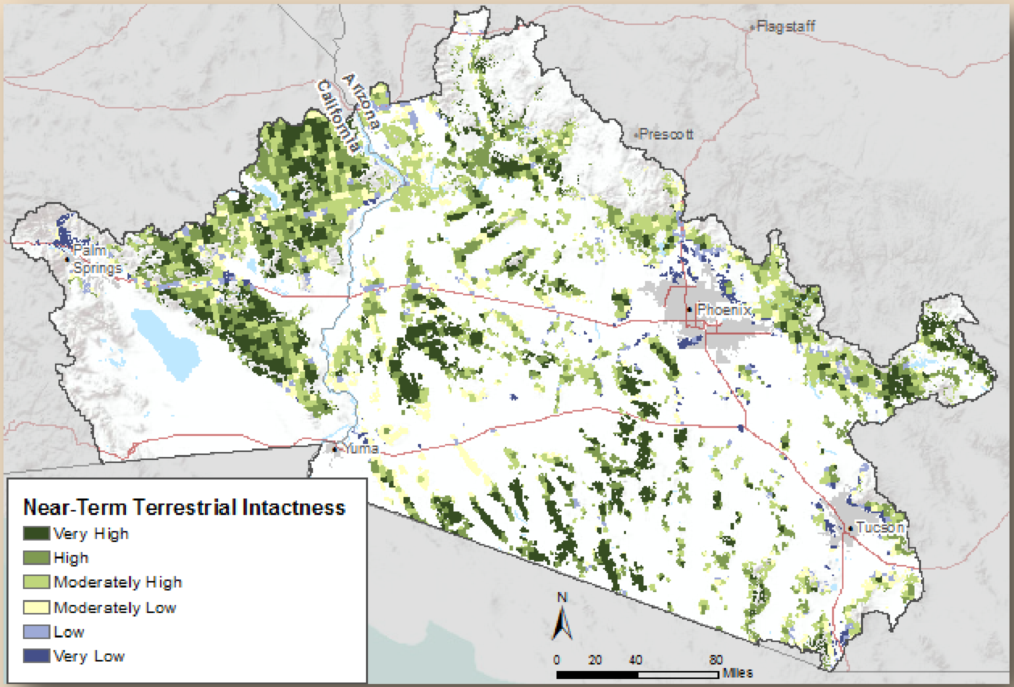


Figure 3. Map shows near-term future status (2025) for Mojave desert tortoise (west of Colorado River) and Sonoran desert tortoise (east of Colorado River). Differences between maps in Figures 2 and 3 are small and difficult to detect; see Figure 4 below for summary histograms.

Similar results were produced for both tortoise species for *near-term future status* (2025, Figure 3) by overlaying current distribution with a mapped model of near-term future landscape intactness to answer the management question, *What terrestrial species are vulnerable to change agents in the near-term horizon, 2025*? Although the intactness model was sound, available predictive data to populate the model was sparse, consisting mainly of renewable energy potential, urban expansion data, and a predictive model for expansion of invasive species. Predictive data was lacking relative to attributes like future roads, utility corridors, recreation, and agriculture. As a result, the regional map for the species' near-term future status (Figure 3) does not show dramatic differences from the current status map. However, summary histograms for Mojave desert tortoise (Figure 4, left) and Sonoran desert tortoise (Figure 4, right) do show small decreases in high intactness classes and modest increases in Low and Very Low intactness for both species in the near-term future (2025).

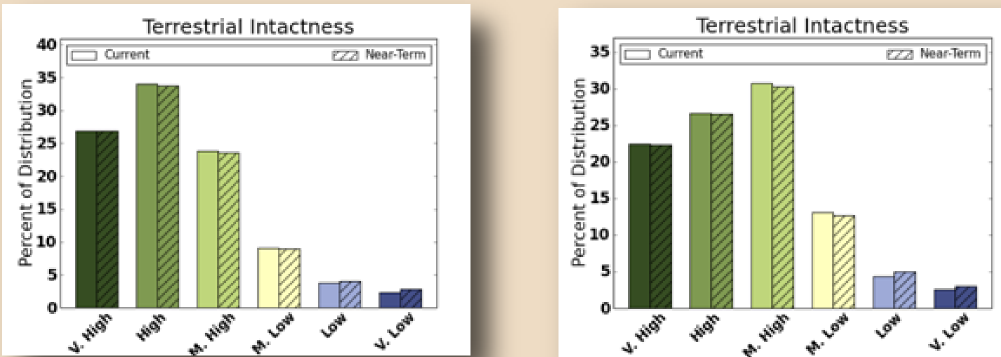
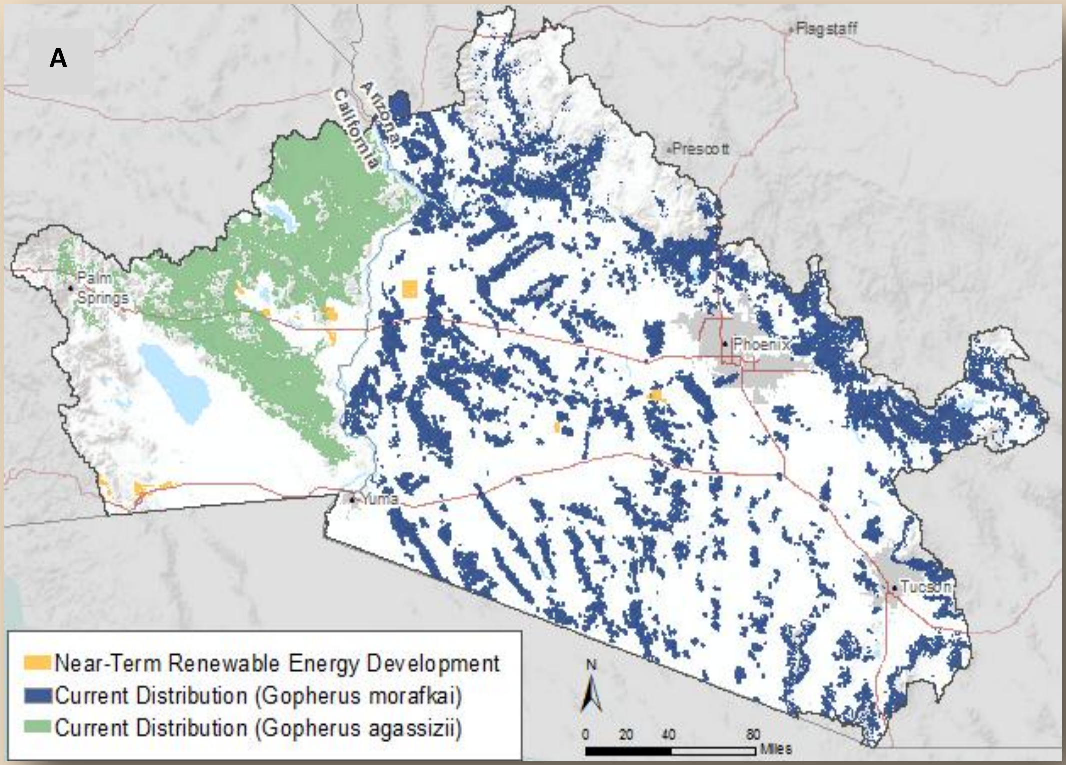


Figure 4. Left: Histogram comparing current (solid color bars) and near-term future (hatched bars) status of Mojave desert tortoise based on comparison of current distribution with current and near-term future terrestrial landscape intactness. Right: Similar results for Sonoran desert tortoise. Both sets of histograms show modest decreases in Very High and High intactness areas countered by slight increases in the Low and Very Low classes.

Future Energy Development Scenarios

REA products included the impacts of near-term future energy development (a component of the near-term terrestrial intactness model, see logic models Section 5.1 and 5.2) on each tortoise species (Figure 5A). Near-term energy development refers to 2011 priority projects that are in the approval process or have already been approved. The Sonoran tortoise, living on rocky slopes, is not likely to have its habitat directly converted for solar energy production, although large scale valley energy development with associated roads and infrastructure will contribute to the further isolation of Sonoran tortoise populations in Arizona. The Mojave tortoise's distribution in the basins of the Colorado Desert puts them in direct conflict with some wind power development as well as prime locations for large (thousands of acres) solar arrays planned for the near future. Projected mid-term energy development (Figure 5B) is not tied to a specific time period, but it is based on those proposed areas still subject to planning and approval. Data for the mid-term energy projection included features from California BLM on verified and preliminary renewable energy rights-of-way, modified solar energy zones (SEZs), and Arizona restoration design energy project data (RDEP). A third category, maximum potential energy development (map not shown) covers a longer time frame and includes more speculative data for wind and solar potential. When the two tortoise species' distributions were overlaid against the maximum potential (renewable) energy development data, Mojave tortoise was shown to be at higher risk of impact than Sonoran, as we would expect (see histograms, Figure 6).

Case Study No. 1



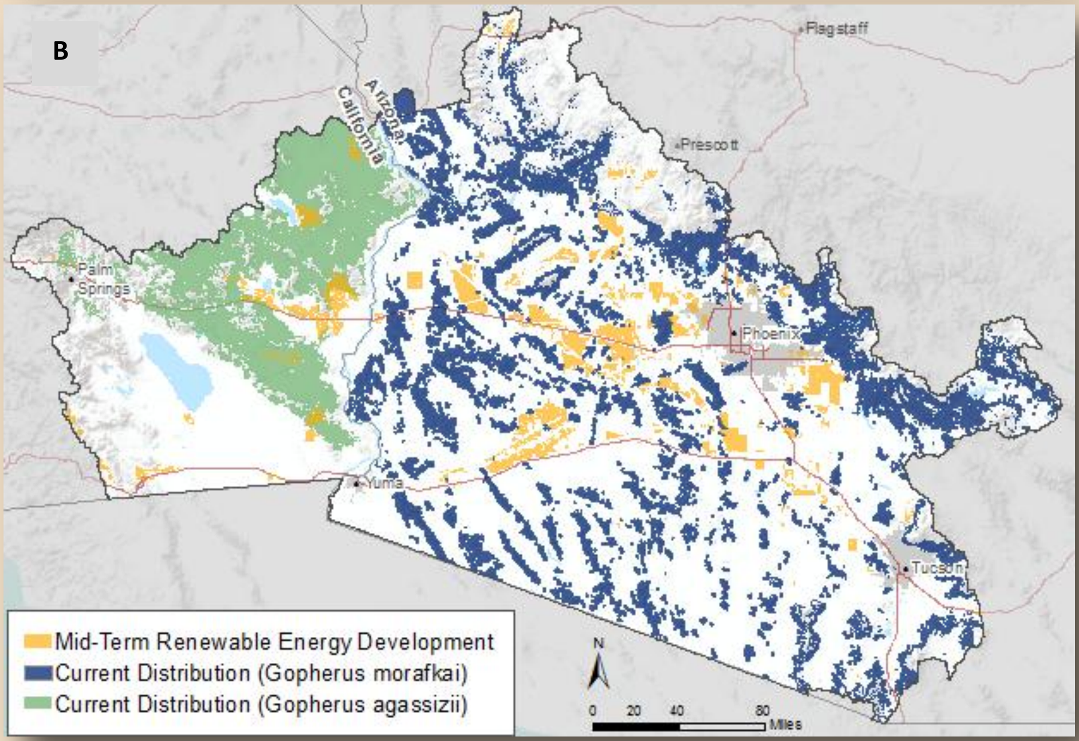


Figure 5. Maps show current distribution for the two species of desert tortoise with data for (A) near-term (2025, 2011 priority projects) and (B) mid-term (see text for definition for proposed development areas) renewable energy development in yellow.

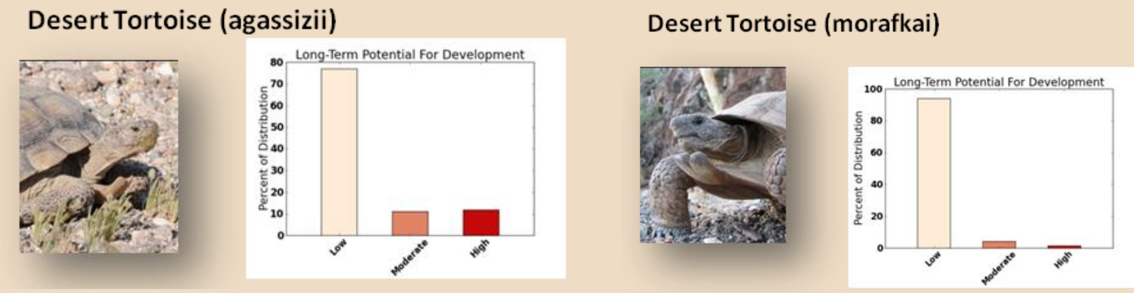


Figure 6. Risks of impacts from maximum potential (long-term) energy development on the two tortoise species, with Mojave tortoise (G. agassizii) experiencing higher risk of impact (left histogram).

The pace of approval and construction of renewable energy projects may be exceeding the state of our knowledge of the effects on various wildlife species (Bare et al. 2009). When considering the effects of major industrial renewable energy projects on desert tortoise, there is some evidence that desert tortoises may be able to adapt to some wind farm development (Lovich and Daniels 2000, Lovich et al. 2011b). Although wind energy facilities fragment the landscape with towers, road network, and associated infrastructure, there is very little road traffic within the sites, and human entry is limited for security reasons. Lovich et al. (2011b) found that the tortoises living in a wind farm near Palm Springs, California did not differ in most demographic characteristics from tortoises living in more natural situations. Thus, while the mortality of birds may be high among arrays of wind turbines (see discussion on golden eagle, Appendix C), desert tortoises may be able to coexist with wind energy, particularly with some pre-planning with tortoises in mind.

Solar energy is a different story. Solar arrays cover thousands of acres, and the land is scraped clean of vegetation. The area of the modified solar energy zones (SEZs) within the REA boundary (data used in the mid-term renewable energy development map, Figure 5B) is about 160,000 acres (DOE/BLM 2012). The largest SEZ area is 148,000 acres in eastern Riverside County, California; 9 projects have been proposed and 2 approved on 57,000 acres of this SEZ as of late 2011. Lovich and Ennen (2011) review the possible effects of industrial solar on desert wildlife and propose research necessary to inform the process and to mitigate the negative effects of solar energy development on wildlife.

Climate Change Scenario (2060)

REA results for climate show the Mojave tortoise under highest risk from climate change (Figure 7). Higher temperatures (estimated to be 2–3°C by 2050) and prolonged droughts may change the suitable elevation range for the species, possibly shrinking its distribution within its present range or prompting a northward or upward elevational shift (Barrows 2011). The low-elevation areas of the Colorado Desert, presently off limits to both species because of high temperatures, extended drought, and low forage value, may expand. The regional view of climate change results for seasonal temperature and precipitation changes suggest a more complex result. Both summer and winter precipitation decline in the 2015–2030 time period, but, for 2045–2060, while winter precipitation shows declines similar to the earlier time period (compared to historic levels), summer precipitation shows smaller declines compared to historic levels. The climate modeling results for vegetation change (based on broad vegetation classes minus human influence, Section 5.4.1.1) show C_4 (warm season) grasses expanding to the west in mid-century, indicating a change in the dominance of winter precipitation in the western Sonoran desert that could affect the Mojave tortoise. On the other hand, higher variability in the bimodal precipitation pattern in Arizona could have a pronounced negative effect on the Sonoran tortoise. A trend toward wetter springs will encourage the expansion of C_3 invasive grasses (cool season grasses such as red brome). If the timing and distribution of the summer monsoon is not radically changed, increasing temperatures will favor native C_4 grasses.

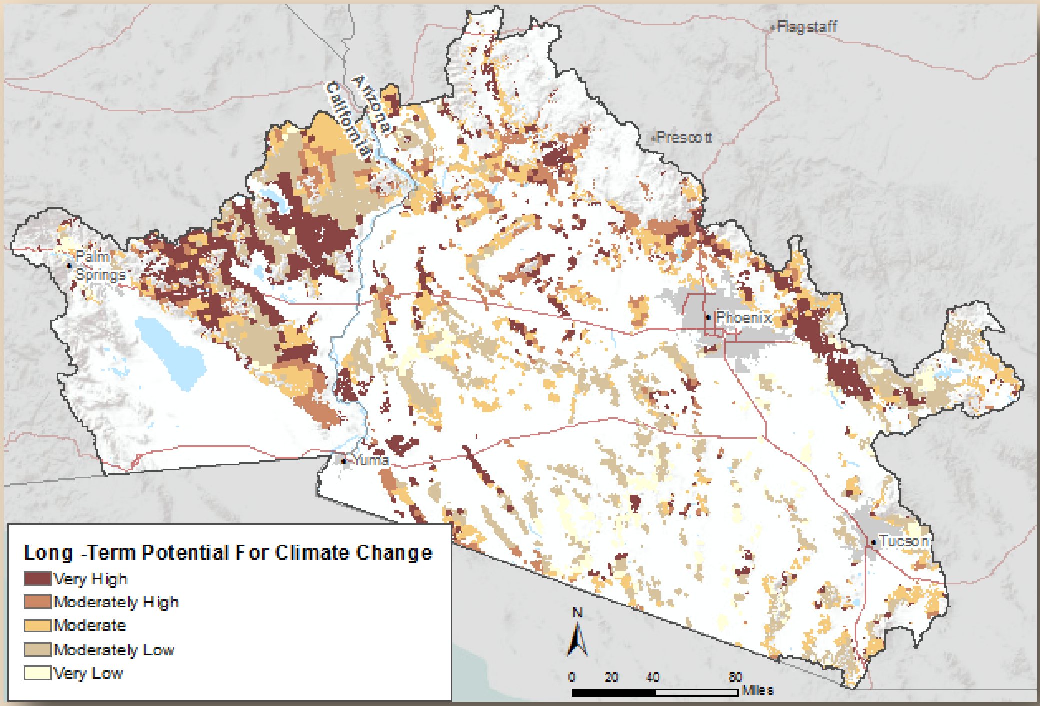


Figure 7. Map results answer the management question, *What terrestrial species are vulnerable to change agents in the long-term horizon, 2060, due to climate change*? The range of the Mojave desert tortoise (west of the Colorado River) is most highly affected by climate change. Mojave tortoises are at the northern limit of the overall range of the various desert tortoise species and populations, and the species is already in trouble; at first glance, one might assume that the Mojave tortoise may be more vulnerable to mortality or extirpation from climate change. However, there may be ameliorating circumstances such as the westward increase in C_4 grasses indicated by the climate modeling results (Section 5.4). Such a change in seasonal precipitation patterns could benefit tortoises in the western Sonoran Desert.

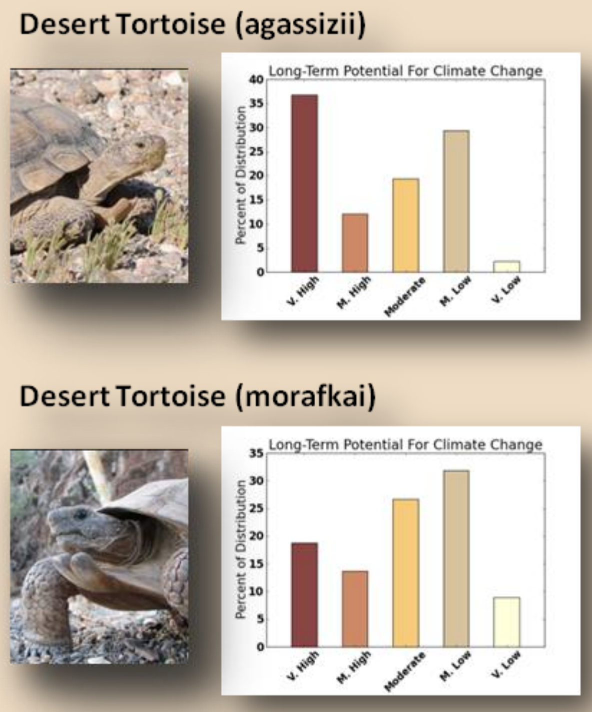


Figure 8. Histogram results for both species of desert tortoise indicating potential climate change impact from Very High (brick color left) to Very Low on the right.

The histogram results (Figure 8) indicate that potential impact on the Mojave desert tortoise is very high with almost half of its current distribution under Very High or Moderately High climate change potential. Sonoran desert tortoise fairs considerably better with roughly 30% of its current distribution within these same categories. Because the desert tortoise exhibits temperature-dependent sex determination of hatchlings, there is concern that increased temperatures from climate change could lead to skewed sex ratios that could affect future populations (Spotila et al. 1994, Baxter et al. 2008). Lewis-Winokur and Winokur (1995) found that the pivotal temperature for desert tortoise sex determination in hatchlings was 31° C. In their experiment, at 31° C, the male to female sex ratio was 5:7; at temperatures below that, the tortoises were all males. Lewis-Winokur and Winokur did not test temperatures above 31° C, but Spotila et al. (1994) did and found that above 32.8° C the hatchlings were all female. It is unknown whether the transitional range of temperature (31–32.8° C; 88–91° F) that produces both sexes (Hulin et al. 2009) is wide enough to allow tortoise adaptation to the increased temperatures that accompany climate change. On the other hand, it has been argued that skewed sex ratios are not found exclusively in stressed turtle populations (Lovich and Gibbons 1990) and that tortoises have survived other periods of temperature extremes in their long evolutionary history. Patterns of hibernation and estivation and the use and placement of burrows also play an important role in tortoise response to temperature extremes and prolonged drought.

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